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EVALUATION OF INSTREAM FISH HABITAT RESTORATION STRUCTURES IN KLAMATH RIVER TRIBUTARIES, 1988/1989

by A.D. Olson and J.R. West

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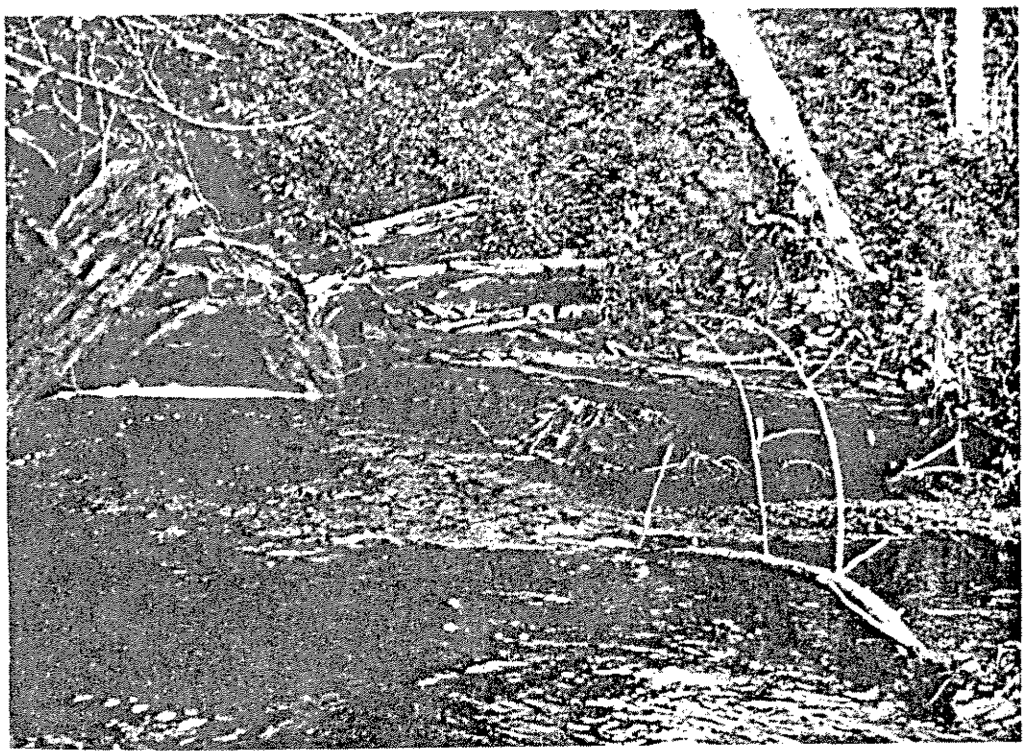

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ABSTRACT

Ten instream fish habitat techniques were evaluated to determine which most effectively restored salmonid spawning and/or rearing conditions. Structure stability was estimated based on how intact each structure remained (by percent) and its age, we then projected useful life for each structure type. Cost in 1989 dollars was used to determine cost per unit habitat area provided. Observed use by spawners was used to estimate total number of redds per structure (over its life). Cost of providing spawning habitat (cost per redd) was calculated by dividing estimated total redds by structure cost.

Habitats resulting from instream structures were classified using the modified Bisson method and we determined the influence zone of each structure using physical variables to define habitat area. Structures were biologically sampled using direct underwater observation techniques described by Hankin and Reeves' (1989). Two person dive teams used a "two-pass" method to enumerate and classify salmonids by species and age-class (0+, 1+ or older juveniles, and adults), noting the presence of other species. Fish use of structure affected habitat (post-modification) was compared to use of habitats like those present prior to structure placement (pre-modification).

Comparison of "pre-modification" and "post-modification" fish standing crops resulted in a "net fish difference" which was

divided by structure cost, yielding "cost per fish reared".

Boulder weirs, the most expensive structures investigated, did not affect enough surface area to make cost per unit of affected habitat reasonable. Cabled cover logs and digger logs (lowest cost structures) were very cost effective at altering physical habitat condition. We believe cost of physically modifying habitat area is only one factor that is important enough to effect success or failure of a large scale habitat restoration program. Assuming all other factors are of equal weight, lowest cost structures can provide the "best value".

Modification prescribed to restore stable spawning habitat needs close scrutiny. We believe it is essential to know how the existing habitat is used by spawners by conducting spawning area use surveys which identify redd location and quantify habitat available during each spawning period. Boulder deflectors were best utilized by chinook salmon spawners, however chinook spawner use of "traditional" structures (weirs backfilled with gravel) was disappointing. **Backfilling of instream structures with suitable gravel is a practice that should be discontinued.** Steelhead spawner use of structures which result in "pocket water" type spawning areas were heavily used. This habitat configuration proved most desirable when woody object cover was readily available to the spawners. **The highest steelhead spawner use was associated with boulder groups with wood and boulder/rootwad groups.**

We found rearing structures which provided high habitat and cover diversity received the best response from juvenile fish. We observed fish use over one summer and saw dramatic unpredictable use changes even through this short time period. Fish rearing needs during other seasons may differ substantially from summer needs, therefore, suitability of modified habitat probably also changes. Digger logs, one of the least costly and simplest structures, provided the best increase in fish standing crop (fish/m^2) for the lowest cost. **We believe digger logs were well used by rearing fish because they are one of the most natural restoration structures investigated.** Other structures which were well used (small weirs, deflectors, and boulder groups with attached wood) also seem to closely duplicate naturally productive habitats. Higher velocity habitat types associated with boulder groups with wood, boulder rootwad groups, and boulder deflectors were selected by juvenile steelhead and chinook salmon. **Providing overhead cover, especially if it extends into the water where it may also be used as object cover, seemed most valuable for juvenile steelhead and salmon if it was placed in a habitat type which would normally receive high fish use.** Placement of object cover in slow velocity areas (pool and glide edges) had questionable value for summer rearing habitat restoration, however we do not know what value these structures may have during colder water high flow periods when fish seek slow velocity, densely-covered habitats.

We defined the most cost effective method as one meeting restoration objectives, providing the greatest increase in fish use (per surface area or volume), over the longest time period, for the lowest cost.

We rank structures evaluated in this study (from most cost-effective to least cost effective) as follows: Digger Logs, Boulder deflectors, Small Boulder Weirs, Boulder Groups with Woody Cover, Free Boulder Weirs, Large Boulder Weirs, Boulder Groups, Boulder/Rootwad Groups, Boulder/Rootwad Deflectors, Small Boulder Weirs, and Cabled Cover Logs.

ACKNOWLEDGEMENTS

We would like to acknowledge all field technicians involved in data collection that made this report possible. Those folks were acknowledged by West, et al (1990) for their contributions to this and another contracted project. Several individuals deserve specific mention for their efforts and help during the field study: Sue Maurer, Melanie Anderson, Larry Schoenike, Chris James, and Ron Taylor spent many field hours collecting information, often under adverse conditions. Linda West provided line drawings for Figures 2 thru 6 which were later scanned into this document by Cal Conklin; we appreciate their efforts, which helped us save some words by using illustrations. Finally, we would like to express our thanks to the Klamath Basin Task Force for providing matching funds which allowed us to evaluate structures in a manner never before possible due to funding limitations.

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INTRODUCTION

The Klamath River system provides habitat for chinook salmon (Oncorhynchus tshawytscha), coho salmon (O. kisutch), steelhead trout (O. mykiss), and other anadromous and non-anadromous species. The upper Klamath system contains salmonid spawning and rearing tributaries of varying size. As a result of reported declines in fish production over past decades, Congress enacted the Klamath River Fish and Wildlife Restoration Act (P.L. 99-552) on October 27, 1986. This law authorized the Secretary of the Interior to restore anadromous fish populations to optimum levels in the Klamath and Trinity Rivers through a program of fish harvest management and habitat restoration.

Prior to enactment of P.L. 99-552 significant investments were made in fish habitat restoration and enhancement by numerous agencies and groups. Most efforts focused on "improving" instream habitat conditions for fish spawning and rearing. A minor investment was made in habitats outside the stream channel. Disproportionately little effort has been expended to evaluate the success, lifespan, or cost-effectiveness of instream habitat manipulations. Furthur, until recently, most instream modifications were made in response to very broad objectives driven by scanty analyses of pre-project habitat conditions. The need to properly evaluate habitat condition prior to prescribing "improvements" is well documented (Everest and Sedell, 1983; Everest, et al, 1986; Bisson, 1988, and others), as is the need to evaluate habitat condition and fish use following modification.

The objective of this project is to determine which of ten common techniques most efficiently modifies instream habitat and elicits a positive response by juvenile and adult salmon and steelhead. The ten methods of habitat modification we evaluated (Table I) are operating in tributaries of the upper Klamath River (Figure 1).

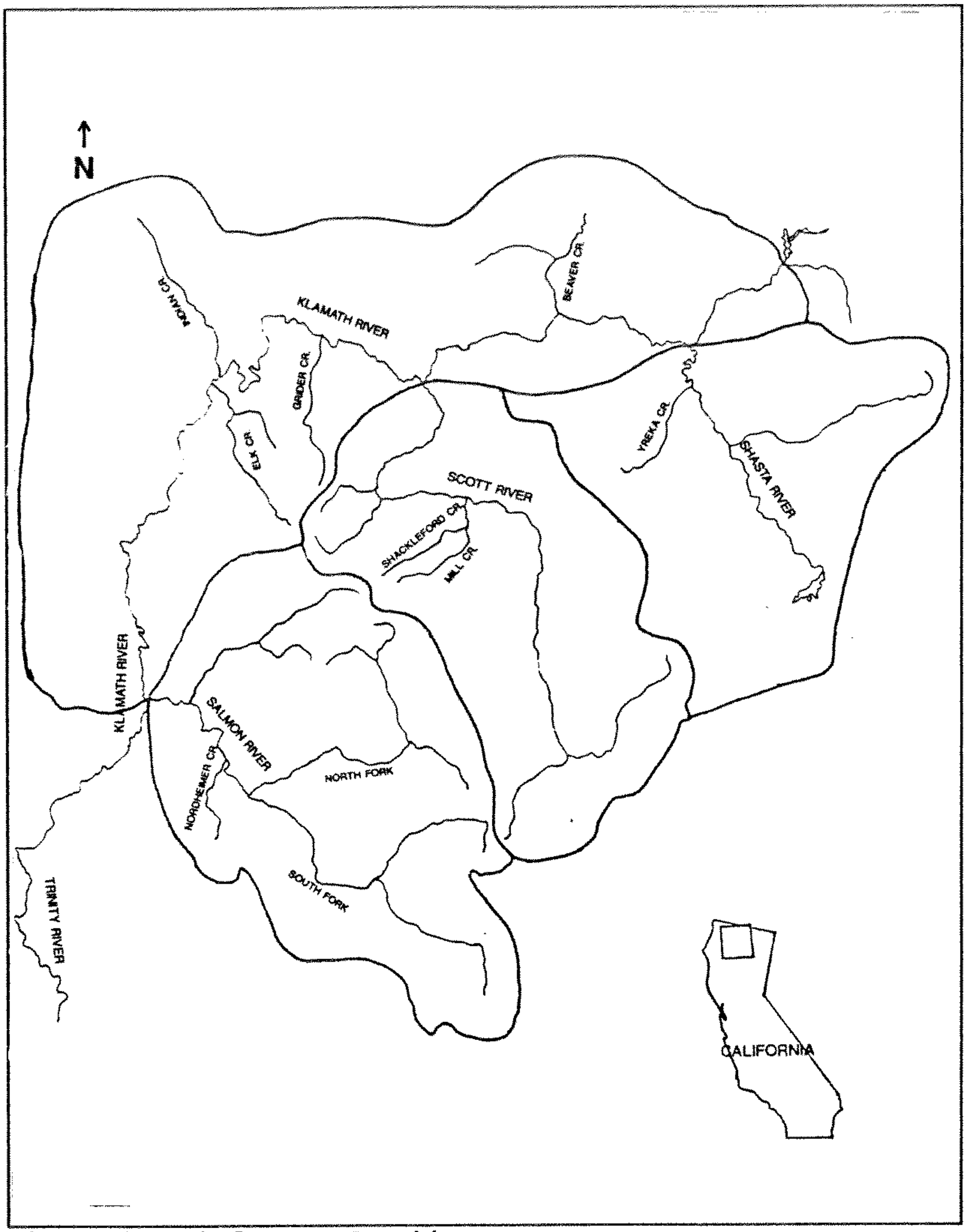

Figure 1. Study Area Location.

The following questions were formulated in an attempt to meet the objective:

a) What physical habitat conditions result from placement of different structure types?

b) What is the Fiscal Year 1989 average cost for placing each structure?

c) What is the estimated structure lifespan (based on present structure condition and age)?

d) To what extent is structural habitat used by adult and juvenile salmonids compared to natural habitats in the same vicinity?

e) Has structural habitat resulted in increased juvenile and adult fish use?

f) Which structure types appear to be most cost effective (based on observed fish use, structure cost, and projected effective structure life)?

Table I Type and Location of Structures Evaluated, 1989.

Structure Type	AKA	No. structures	Location
Digger Log	DLG	6	Mill Creek
Cover Log	CCL	10	Salmon, S.& E. Fks.
Free Bldr. Weir	FBW	5	Elk Creek
Lge Bldr. Weir	LBW	6	Salmon, S. Fk.
Sm. Bldr. Weir	SBW-I/B	6	Indian & Beaver Creek
Boulder Groups	BLG	10	Indian Creek
Bldr. Gps&Wood	BGW	10	Salmon, S. Fk.
Bldr./Rtwad Gps	BRG	10	Salmon, S. Fk.
Bldr. Dflctrs	BLD	5	Salmon, S. Fk.
Bldr/Rt.Dflctrs.	BRD	5	Salmon, E. Fk.

DESCRIPTION OF STUDY AREAS

General

The study areas described below are included in a broader "contract study area" described by West, et al (1990), except East Fork of South Fork Salmon River and Mill Creek (Figure 1). Reaches within the "contract study area" were used for spawning and rearing comparitive purposes. We assumed that using the broader contract study area in effect increased the sample size and should result in a higher degree of accuracy.

South Fork Salmon River

The South Fork Salmon study area is located in the upper portion of the basin. Flows fluctuate dramatically, and have ranged from a fall base flow of about 0.98 cubic meters per second (cms) (35 cubic feet per second (cfs)) to an estimated high of 252 cms (9,000 cfs) since 1979. Cabled cover logs, large boulder weirs, boulder groups with wood, boulder/rootwad groups, and boulder deflectors (Table 1) were located in the "Gibson" and "Petersburg" reaches (West, et al. ,1990).

The "Gibson" reach is confined by bedrock banks that control channel features during high discharge. Riparian canopy is dense through most of the area, composed of a mix of conifer and deciduous species that provide stream shade. The "Petersburg" reach is a poorly confined channel that flows through a broad floodplain which is probably a remnant of past hydraulic mining activities and floods, as recent as 1964, and has poor riparian vegetative condition. The channel is wide and shallow for much of the reach and little shade is available. Water temperature increases substantially between the top and bottom of the reach. Deep pools are rare due to the mobile nature of the stream bed, and they are associated with bedrock encroachment in the active channel. Extensive instream habitat restoration activities (including the above cited projects) have occurred in this reach since 1982.

East Fork of South Fork Salmon River

The East Fork of South Fork Salmon River study area extends from its confluence with South Fork Salmon River upstream about 1.5km to Ketchum Gulch. Cabled cover logs and boulder/rootwad deflectors were located in this study reach. The "East Fork" study area is moderately confined by well vegetated banks and a dense riparian area. Higher velocity habitats dominate the stream, however a variety of pools are available to juvenile and adult salmon and steelhead. Instream habitat restoration activities were prescribed by a habitat assessment conducted in 1987 which found adequate spawning habitat available and some areas where rearing conditions were damaged by past flooding (West, et al., 1988). Instream structures were placed in summer 1988 and 1989. Structures evaluated in this report were placed in 1988.

Elk Creek

Elk Creek, a mid-Klamath tributary originating in the northern slopes of the Marble Mountains, enters the Klamath River one mile downstream from Happy Camp (elev. 1040). The Elk Creek watershed is situated entirely within the Klamath National Forest.

Bio-enhancement efforts consisting of stocking and rearing began on Elk Creek in 1984. CDF&G and the Karuk Indian tribe have cooperatively operated a juvenile chinook rearing facility with the capacity to produce 40,000 smolts annually. Between 24,000 and 28,800 yearling coho salmon have been planted in Elk Creek annually since 1986. Small numbers (<4500) of steelhead fingerlings have also been planted periodicly in Elk Creek and its tributaries.

Instream restoration efforts begun in 1985 include boulder weirs and boulder groups. Free-boulder weirs, constructed in 1985, were included in the structure evaluation (Table 1). All instream restoration efforts undertaken prior to this study on Elk Creek have been located within "Reach II" (West et al.,1990).

"Reach II" is a 2.5 km section located between stream km 5.6 and Twin Creeks. The channel is moderately confined and secondary channels are common during periods of high flow. This relatively flat stream reach has been influenced by floods as recent as 1964. The riparian canopy consists of conifer and deciduous species, but mature conifers are limited to the upper banks. Cobble and small boulders dominate streambed substrates.

Indian Creek

Indian Creek originates on the east slope of the Siskiyou Mountains and flows southeast to its confluence with the Klamath River at Happy Camp (elev. 1060). The drainage basin is located entirely within Klamath and Siskiyou National Forest boundries.

Bio-enhancement efforts have been conducted here since the early 1980's. Instream resoration efforts begun in 1982 consist of boulder weirs, boulder groups, and boulder deflectors. All structures were constructed within the "School House" reach (West et al.,1990). Boulder weirs and boulder groups located within this reach were evaluated.

The "School House" reach extends from stream kilometer 15.5 to West Branch Creek. This moderately confined reach maintains a flat gradient throughout with riffles and runs dominating the habitat features. Adequate stream shade is provided by a deciduous canopy. Hydraulic mining, logging, channelization, floods, as recent as 1964, and post-flood in-channel timber salvage are evidenced by large unvegetated flats adjacent to the creek.

Mill Creek

Mill Creek is tributary to Indian Creek with its confluence located in the "School House" reach. Mill Creek originates on the south slopes of the Siskiyou Mountains and flows south 10.5 km to the confluence. The study reach extends from stream kilometer 1.8 to 2.6. The channel is moderately to well confined and maintains a moderate gradient throughout the study reach. Step run (type 16) and lateral scour pools associated large wood (types 10 and 11) dominate the habitat. Excellent stream shade is provided by a dense riparian canopy of alders (Alnus sp.). Instream restoration activities performed in 1988 includes use of existing materials to form digger logs increasing cover and pool habitat. Six digger log structures were evaluated within this study reach.

DESCRIPTION OF STRUCTURES

Cabled Cover Logs are single whole conifer or deciduous trees cabled to bedrock and suspended within the habitat unit. The objective of placing these structures was to provide cover within the habitat and overhead for juvenile rearing fish. Cabled cover logs were anchored to bedrock with 1/2" diameter galvanized cable epoxied to holes drilled in the bedrock. These structures are located on South Fork and East Fk. of South Fork Salmon River in main channel and lateral scour pool habitats.

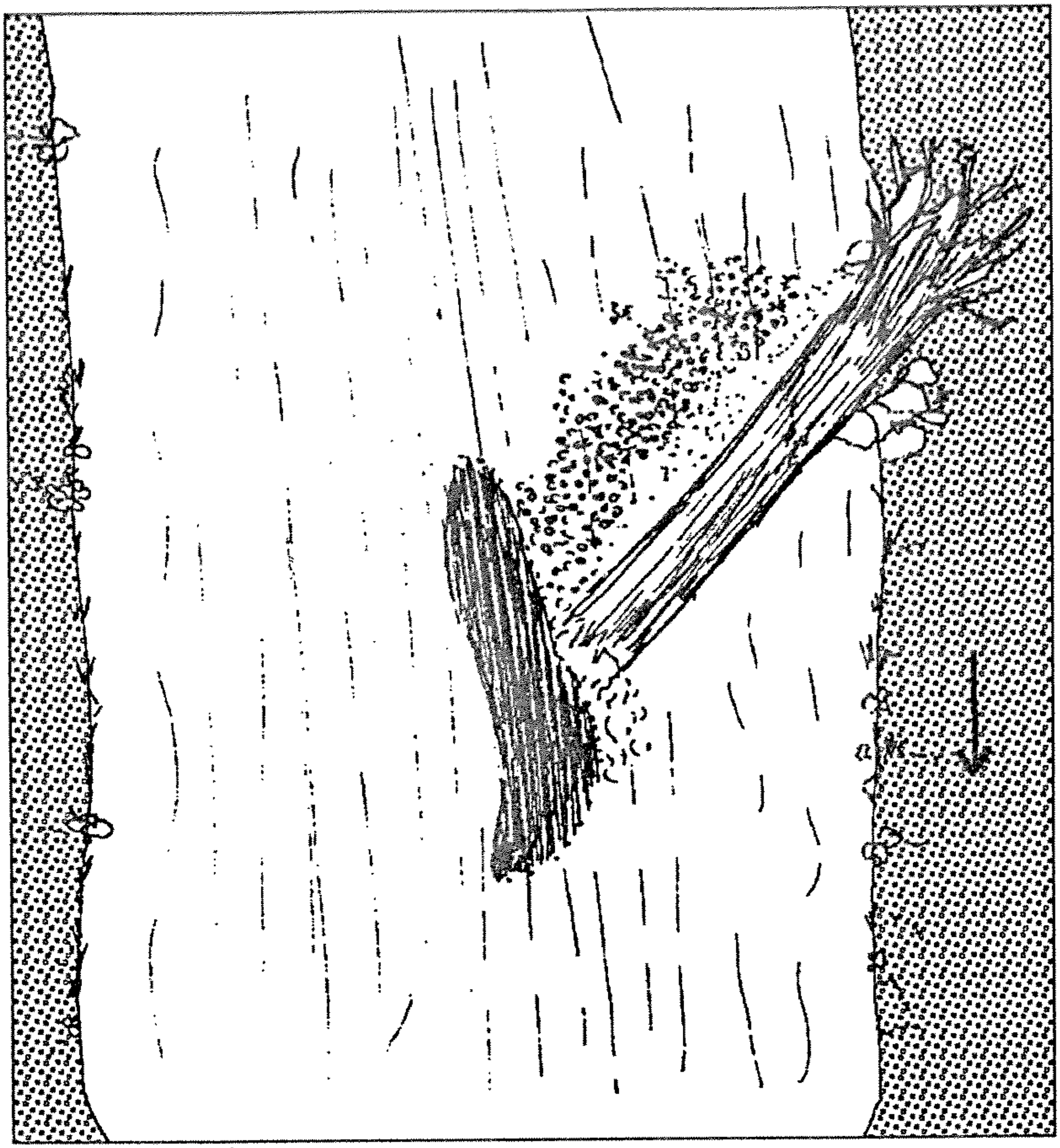

Figure 2. Digger Logs

Digger Logs are large single tree boles with or without attached rootwad that have been skidded into the stream channel (Figure 2). A large percentage of the tree bole remains on the bank, acting as an anchor, and the portion within the channel provides overhead cover as well as structurally diversifying instream habitat. The principal objective of prescribing placement of these structures in Mill Creek (tributary to Indian Creek) was to enhance juvenile rearing habitat.

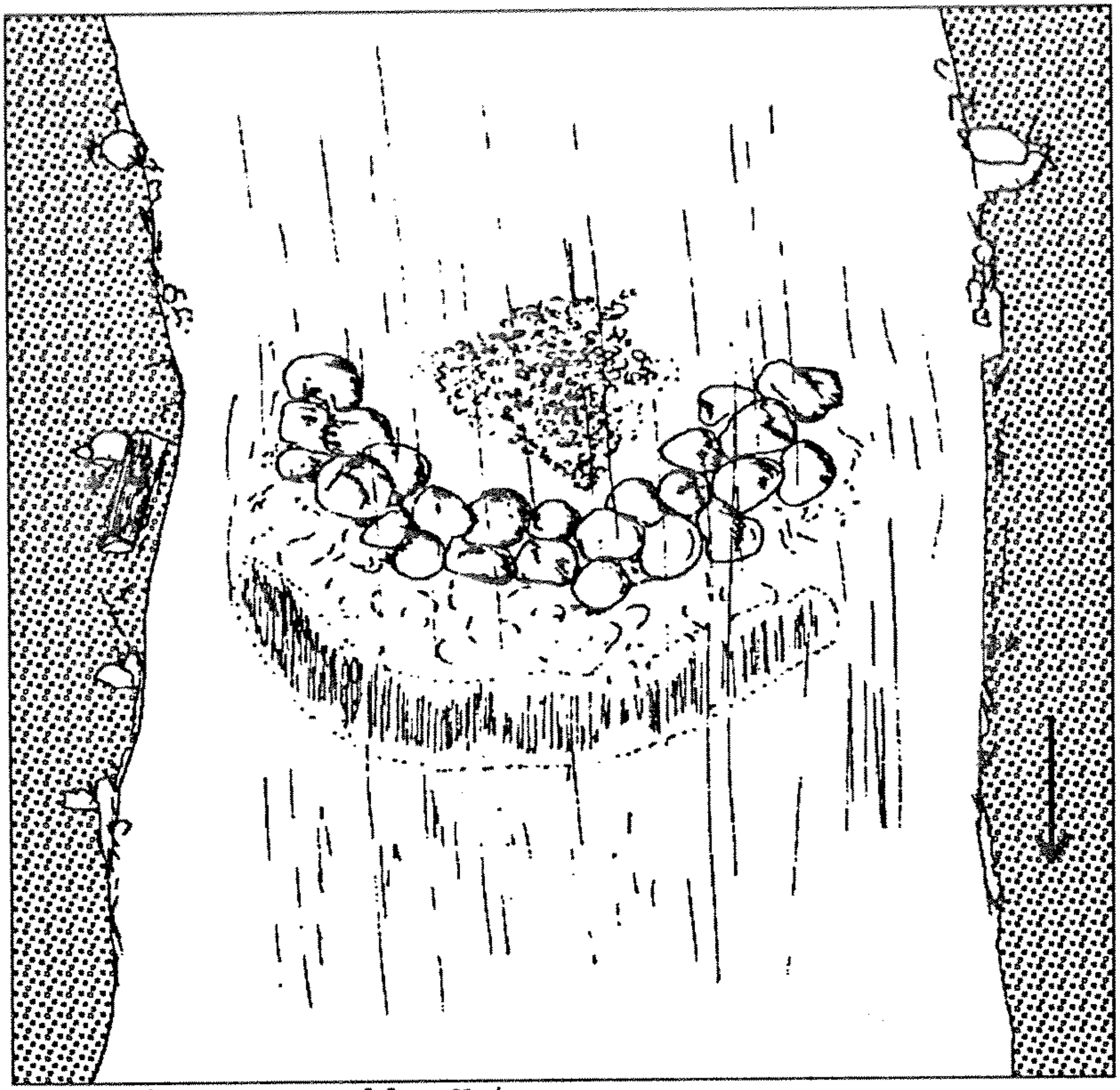

Figure 3. Free Boulder Weir

Free Boulder Weirs are structures that do not completely span the stream channel (Figure 3). The objective of these weirs, located in Elk Creek, was to provide juvenile rearing habitat and stable spawning areas for chinook salmon and steelhead.

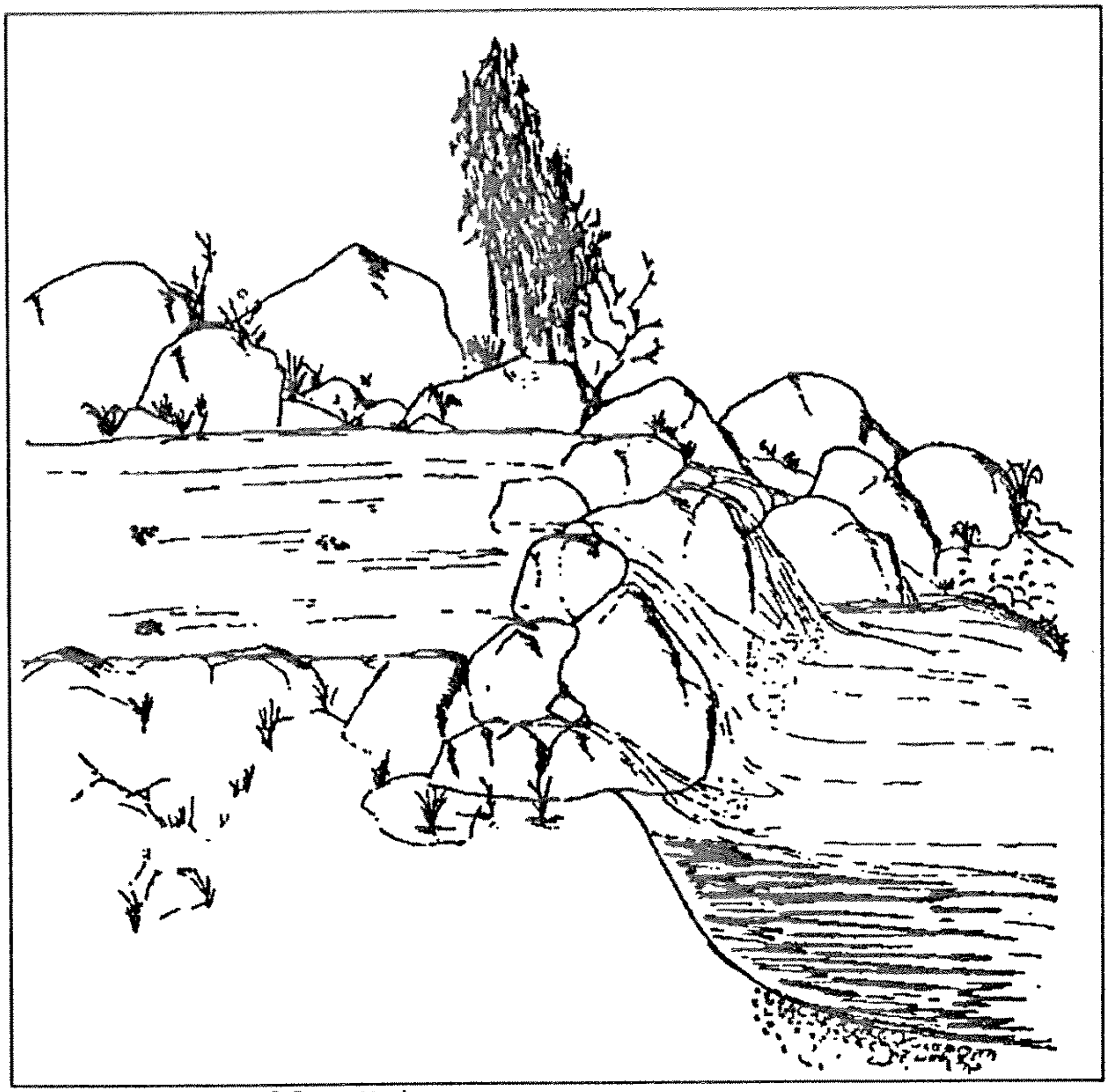

Figure 4. Boulder Weir

Boulder Weirs are structures that completely span the stream channel (Figure 4). Large weirs were located in the South Fork Salmon River, small weirs were located in Beaver Creek and Indian Creek. These structures can be placed diagonally across the channel, or in more traditional upstream or downstream pointing "V" configuration. The objective of these structures was to provide more diverse juvenile rearing habitat and stabilize transitory spawning gravels. Beaver Creek weirs were constructed specifically to provide spawning habitat, they were backfilled with spawning gravel.

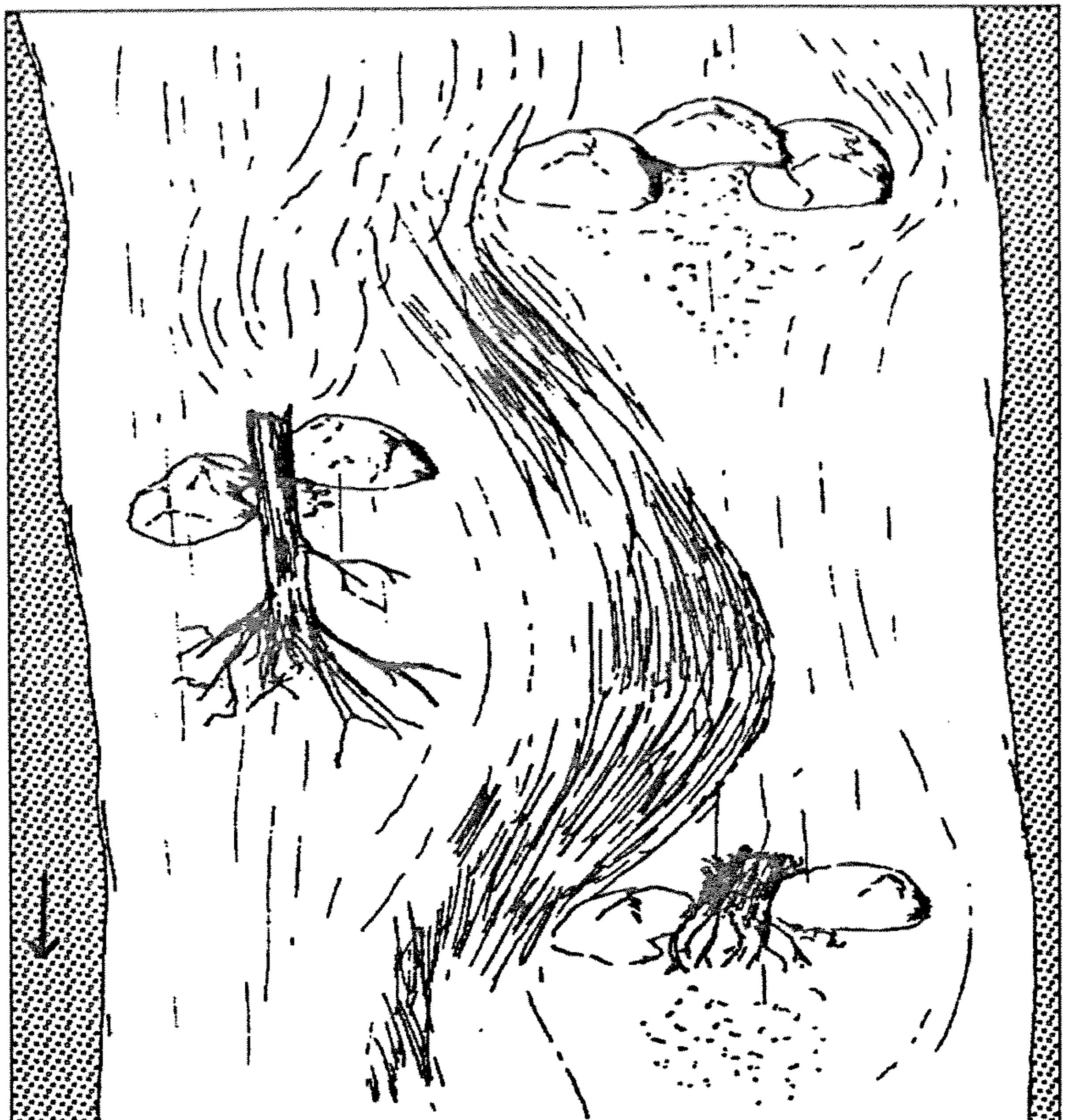

Figure 5. Boulder Groups, Boulder Groups with Wood, and Boulder Rootwad Groups.

<u>Boulder Groups, Boulder Groups w/wood, and Boulder/Rootwad Groups</u> are small structures usually placed in groups of several to several dozen (Figure 5). These structures were placed in low gradient riffle habitats on Indian Creek and South Fork Salmon River (respectively), to provide diverse juvenile fish rearing habitat. Wood debris and rootwads were added to these groups in an effort to provide more complex cover and increase fish standing crops.

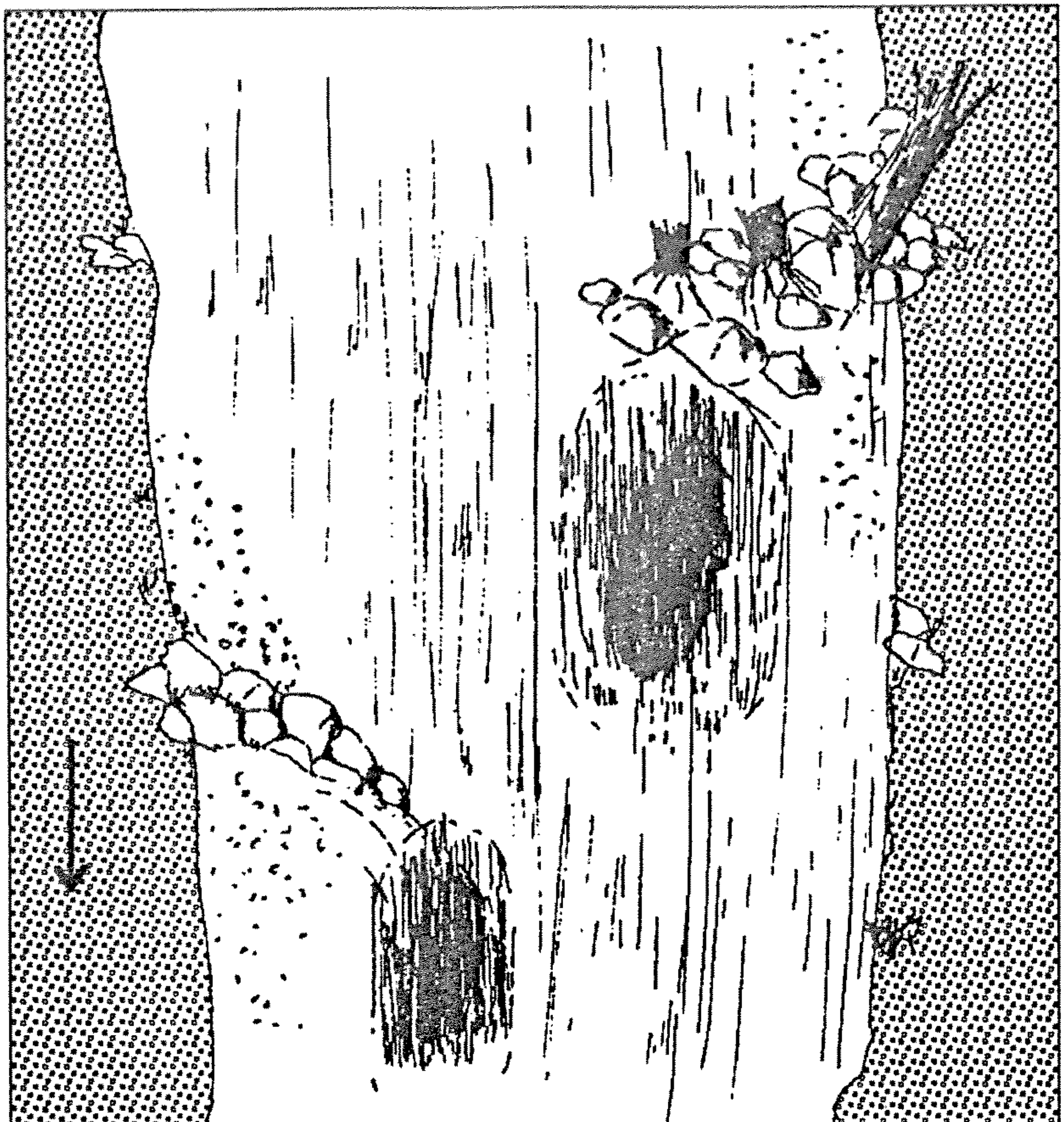

Figure 6. Boulder Deflector and Boulder/Rootwad Deflector.

Boulder Deflector and Boulder/Rootwad Deflectors are small bankside structures (Figure 6) placed in riffle or run habitats to encourage channel deepening and habitat diversification. These structures were placed in the South Fork Salmon River and The East Fork of South Fork Salmon. The objective of structure placement was to provide rearing habitat adjacent to the structure (high velocity scour pool habitat) and stable spawning habitat on the upstream edge of the structure.

MATERIALS AND METHODS

Structure Selection

Evaluation structures were randomly selected from all similar structures in place at the beginning of the assessment. We agreed to evaluate a given number of structures of each type (Table I) prior to beginning this study. If ten structures of a given type were to be evaluated in an agreed upon area that contained 100 such structures, evaluation structures were chosen using a 10% random sample on the first visit to the site.

Structure Condition and Cost Evaluation

Each structure was visited several times during the summer of 1989 to assess conditions at variable discharge stages. Physical condition of each structure was determined on the first field season visit. Structure stability was evaluated according to how intact each structure remained (by percent) and the age of each structure. We then projected useful life for each structure type based on results of structure stability evaluation (eg: if a 3 year old structure was 80% intact, we assumed a maximum structure life of 15 years). Cost in 1989 dollars was estimated by determining the cost of placement and adjusting for inflation. Cost per unit habitat area (CPU) represents the cost of providing habitat during the estimated lifespan of a structure; the following formula was used for this calculation:

$$CPU = \text{Structure Cost} / (\text{Surface Area} * \text{Structure Life})$$

Spawning Ground Evaluation

Each study area was surveyed during spawning season (salmon: October through mid-December; steelhead: March through mid-May) at biweekly intervals by two-person crews. Numerous structures, in addition to those specifically evaluated for this study, were in place in the contract area and their use was observed during spawning surveys. Spawner utilization therefore is based on a sample size much larger than shown in Table 1. We assumed this increased sample size would lead to a broader but more accurate view of structure use by spawners.

Redds were enumerated using the method described by West, et al (1990). The habitat type (McCain, et al, 1990) associated with each redd was identified. Redd densities (number of redds per square meter) by species were calculated for each structure type by dividing the number of redds associated with each structure by the available spawning area for that type.

Total number of redds per structure (over its life) was estimated by employing the following technique:

TTl redds=(redd density*spawn surf./structure) * str. life

Cost per redd was calculated by dividing total redds (chinook and steelhead) by structure cost.

Habitat specific spawner "utilization coefficients" were developed using the formula described by Bisson et al. (1982) in order to "relate the fraction of the population found within a particular habitat type to the relative abundance of that habitat type" in the study area. The formula and its usage is described in greater detail by West, et al. (1990).

Coefficient values can range from -1 to positive infinity; a negative value indicates that use of a specific habitat for spawning is less than average use. A positive value indicates habitat specific spawning use greater than average. A value of 0 indicates that the specific habitat is being used in proportion to it's occurrence. Some reaches were uncountable at times, especially during steelhead spawning, due to adverse viewing conditions.

Rearing Habitat Evaluation

Unmodified stream habitat surveyed at base summer flow in 1989 was classified into one of 22 possible habitat types utilizing the system originally described by Bisson, et al. (1982) and later modified by McCain, et al (1990). West, et al. (1990) describes the general method employed.

Habitats resulting from instream structures were classified using the same method, however the criteria used to define a habitat unit was reduced to equal or exceed one-quarter the width of the wetted channel. This "project-level" typing allowed for finer definition of habitats associated with structures. We ocularly determined the influence zone of each structure using physical variables (eg: water velocity, substrate composition, and water depth) to aid in defining habitat area affected by each structure.

Physical measurements, taken once during the contract period for each habitat unit, included mean unit length, width, and depth, maximum depth, and depth at riffle crest. We ocularly estimated spawning area and amount of cover available to fish in each unit (of that total, the percentage of each cover type: undercut banks, small woody debris, large woody debris, terrestrial vegetation, aquatic vegetation, white water, boulders, and bedrock ledges). Spawning area suitability was determined using depth, velocity, and substrate suitability criteria described by

Reiser and Bjornn (1979). Spot air and water temperature and estimated streamflow (cfs) were recorded during each visit. We ocularly estimated substrate composition (percent fines, gravel, cobble, boulder and bedrock), mean substrate embeddedness, percent exposed substrate, and percent stream shade at noon.

Each structure type was biologically sampled several times throughout the contract period using direct underwater observation techniques described by Hankin and Reeves' (1989). Biological sampling was conducted by two person dive teams using the equivalent of a "two-pass" method beginning at the downstream end of each dive unit. Salmonids were classified by species and age-class (0+, 1+ or older juveniles, and adults). The presence of other species was noted. This method was calibrated against electrofishing results (West, et al.,1990).

Mean densities (#/m^2) of observed salmonids by age-class and species were calculated for each unit. Estimated densities were derived for each habitat type by applying the appropriate factor based on results of electrofishing calibration (West, et al, 1990). Estimated densities were used to perform all analyses and interpret results.

Estimated densities were converted to estimated standing crop of all species and age classes of fish for each structure type by multiplying estimated fish density (number of fish/unit area) by structure affected surface area. Fish use of structure affected rearing habitat (post-modification) was compared to use of habitats of the same type which were present prior to placement of the structure (pre-modification).

Comparison of "pre-modification" and "post-modification" fish standing crops resulted in a "net fish difference". Net fish difference was divided into 1989 structure cost, yielding a cost per fish reared. **Cost per fish reared is not species or age class specific and this value does not imply that all fish observed survive to smolt. We offer this value for comparative purposes (between structure types in this evaluation) only and it should be assumed as a minimum cost per fish reared for each structure type.**

Habitat specific juvenile fish rearing "utilization coefficients" were calculated using the formula described by Bisson et al. (1982) in order to "relate the fraction of the population found within a particular habitat type to the relative abundance of that habitat type" in the overall study area. The formula used is identical to that referenced in spawning ground evaluation methods, except, numbers of juvenile fish per unit area were substituted for number of redds per unit area. Coefficients were calculated for utilization of habitat types based on the study reaches previously described.

RESULTS

Cover Logs were placed adjacent to existing pool habitats and did not result in physical habitat changes except degree of cover complexity and composition (Figure 7). Cost per unit habitat area was lower than the majority of other structures ($0.067). Fewer juvenile fish were observed in structure affected habitats which resulted in loss of "cost per fish reared" (Table II). However, yearling and older juvenile steelhead were the only species and age class that selected these structures as indicated by the positive utilization coefficient (Table III). We observed adult salmon and steelhead using these structures, however we did not investigate potential changes in spawner use because the structure objective was enhancement of juvenile fish rearing conditions.

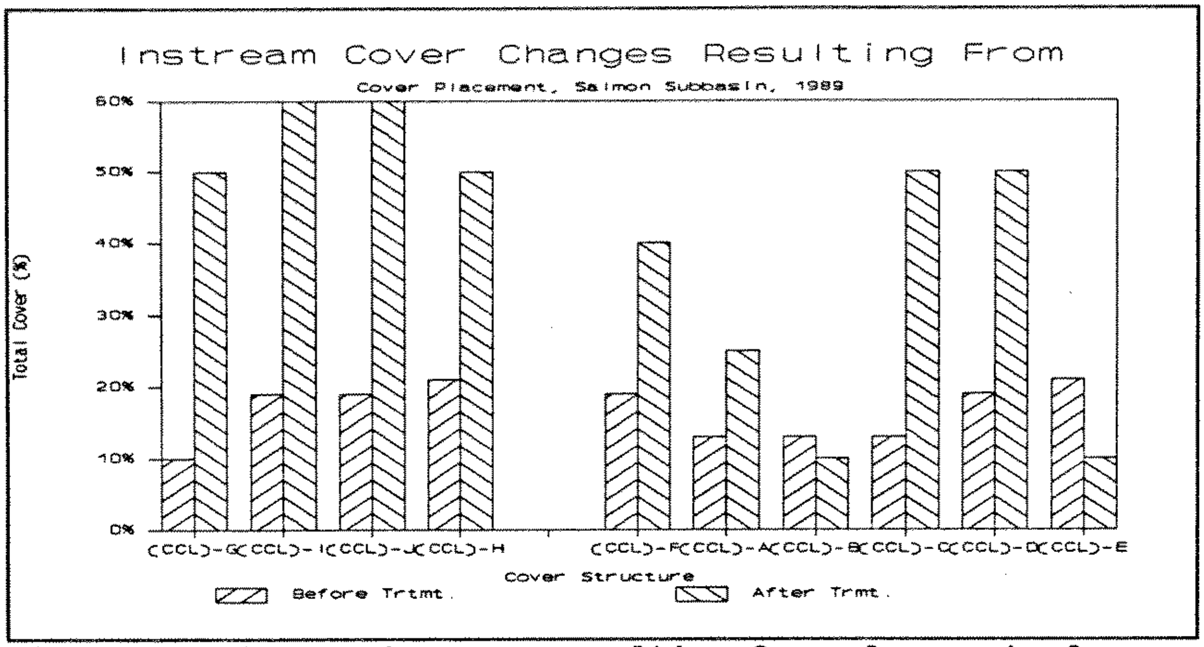

Figure 7. Changes in cover resulting from placement of cover logs, Salmon Subbasin 1989.

Digger Log structures increased available instream object cover in nearly all cases beyond what was available in control areas (Figure 8). In several instances cover was reduced because water velocities were slowed and water surface turbulence was lost. Cost per unit habitat area was lowest of any structure we evaluated ($0.050). We did not investigate potential changes in spawner use because the structure objective was enhancement of juvenile fish rearing conditions. In addition to cover changes, these structures diversified Run habitat by forming backwater and

Table II. Summary of Structures and Variables Evaluated, Klamath Basin 1989.

STRUCTURE	COST	LIFE	AREA (M^2) per Struc.	FISH/YR.	COST/FISH
Cover Log	$90	25	54	-1.3	($2.69)
Digger Log	$60	57	21	16.4	$0.06
Free Weir	$1900	25	204	43.5	$1.75
Large Weir	$2100	18	323	65.7	$1.78
Sm. Weir(BV)	$6825	40	174	24.1	$7.08
Sm.Weir(IN)	$2280	56	154	98.5	$0.41
Bo.Grp.	$345	50	109	11.0	$0.63
BG Wood	$290	25	23	6.8	$1.71
Bo/Rt Grp.	$290	20	39	5.5	$2.64
Bo. Defl.	$290	50	70	12.0	$0.48
Bo/Rt Defl.	$290	50	16	3.3	$1.76

Table III. Juvenile Salmon and Steelhead Rearing Utilization Coefficients for Instream Structures, Klamath Basin 1989.

	Utilization Coefficient			
Structure	0+ Sthd	1+ Sthd	0+ King	0+ Coho
CCL	-0.6604	**0.5938**	-0.2500	N/A
DLG	**0.5916**	**0.4161**	N/A	N/A
FBW	-0.6247	-0.7790	-0.3917	0.0000
LBW	-0.6310	-0.2009	-1.0000	N/A
SBW-B	**0.7425**	-0.4240	-0.3943	-1.0000
SBW-I	-0.0974	**0.0779**	-1.0000	**5.9490**
BLG	-0.2392	-0.4753	-0.4458	-0.4388
BGW	**0.1509**	**3.3797**	**20.1250**	N/A
BRG	**2.2956**	**1.0706**	**39.1250**	N/A
BLD	**4.5807**	**0.2362**	**7.1667**	N/A
BRD	-0.4920	-0.6050	-0.5410	N/A

midchannel pools. Increased juvenile fish useage combined with the low cost per structure and long estimated structure life, resulted in the lowest **"cost per fish reared"** of any structure investigated (Table II). Young-of-the-year and yearling steelhead selected this modified habitat for rearing (Table III), no salmon were found rearing in this small stream.

Free Boulder Weirs dramatically shifted habitat from low gradient riffle to a mix of types predominated by slow velocity glide habitat (Figure 9). Available habitat volume was reduced 14% because reduced velocities allowed gravel filling and depth reduction. Cost per unit habitat area was moderately high, even for weirs, the most expensive structures assessed ($0.373).

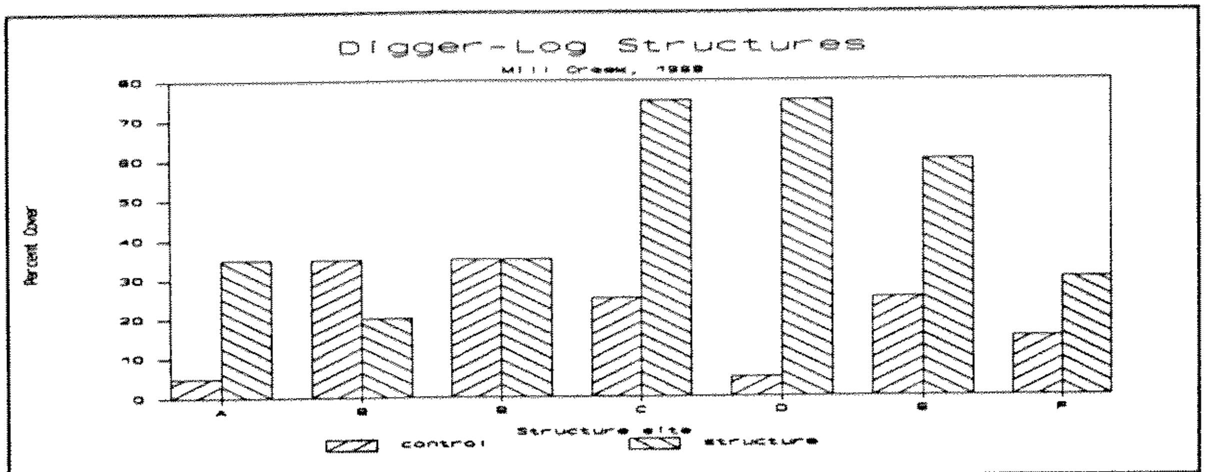

Figure 8. Cover differences between digger log sites and control areas, Mid Klamath Subbasin 1989.

Gravel filling resulted in an increase in available spawning area (Figure 10). Chinook and steelhead spawners used gravels associated with these structures, but they did not select that habitat strongly as evidenced by utilization coefficients near 0 (Figure 11;Table IV). If that rate of use continued over the estimated life of these structures, spawning habitat would be provided at a reasonable rate ($4.29/redd; Figure 12;Table IV) compared to some other structure types investigated.

Though habitat volume was reduced, juvenile fish use increased, as a result of increased habitat diversity. Increased juvenile fish use resulted in a relatively high cost per fish reared ($1.75; Table II). None of the species or age classes of juvenile fish present selected this structure habitat over naturally available habitats (Table III).

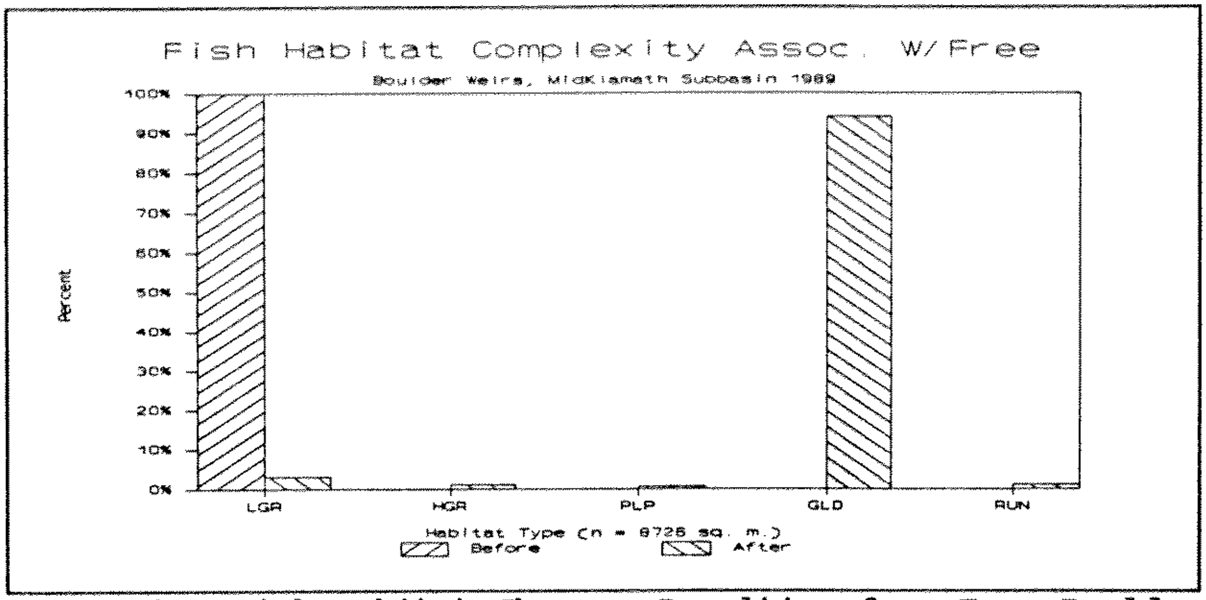

Figure 9. Fish Habitat Changes Resulting from Free Boulder Weirs, Mid Klamath Subbasin 1989.

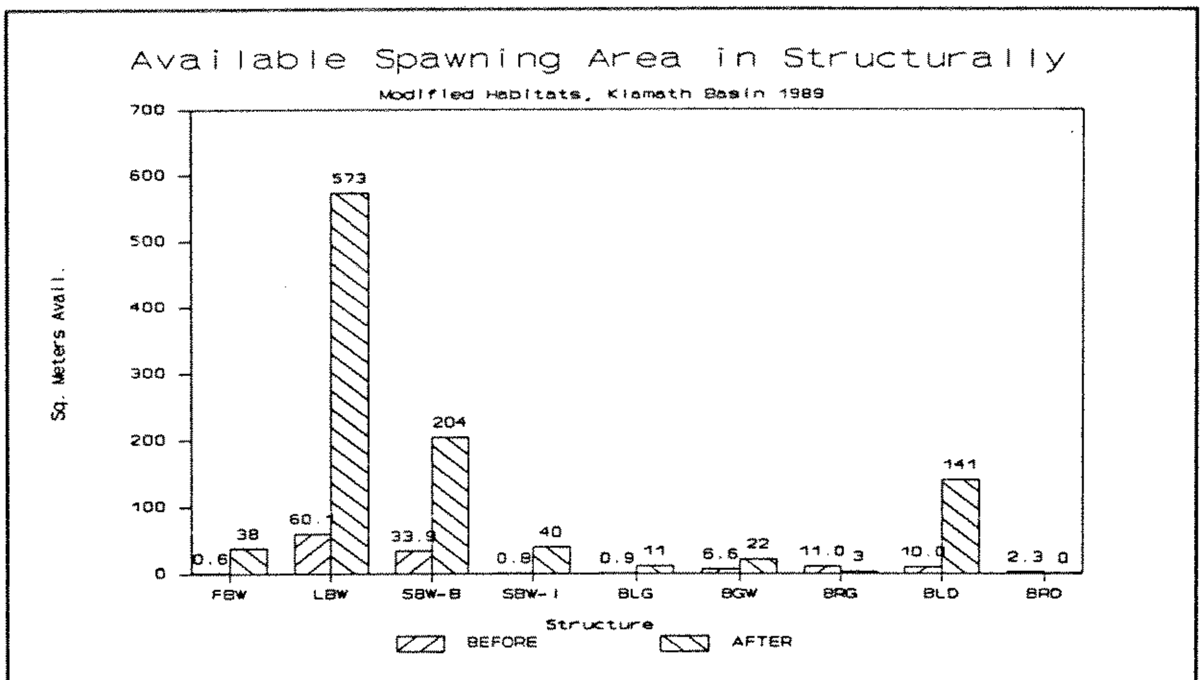

Figure 10. Changes in Spawning Area Availability Resulting from Instream Fish Habitat Restoration Structures, Klamath Basin 1989.

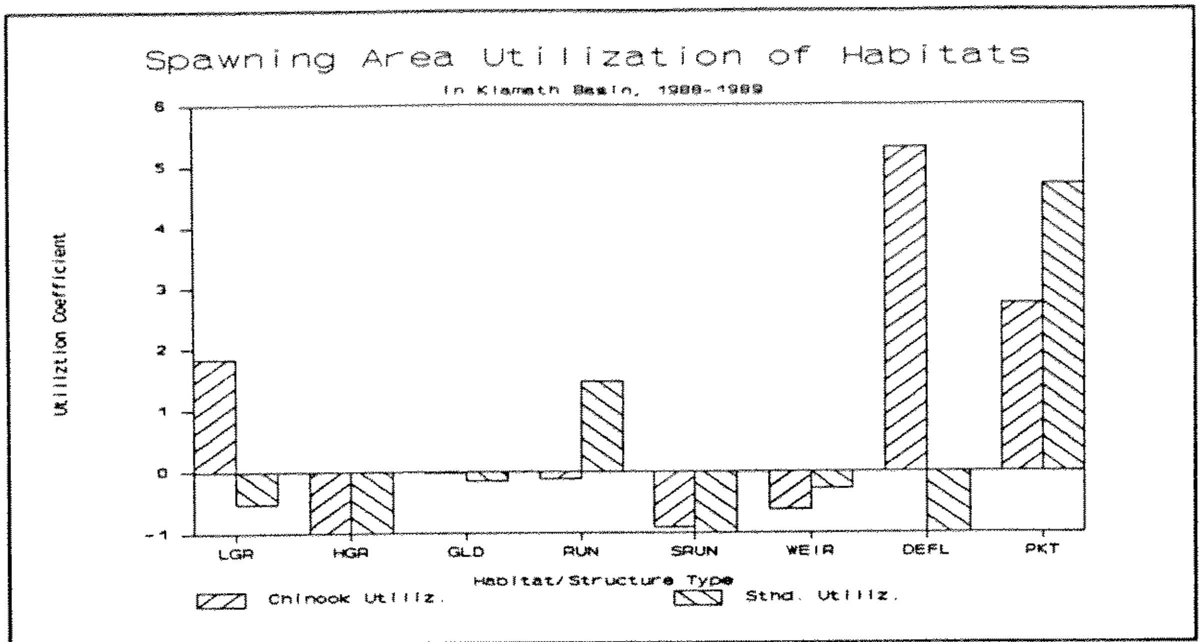

Figure 11. Salmon and Steelhead Spawner Utilization of Modified and Unmodified Habiatats in Structure Evaluation Study Area, Klamath Basin 1988 and 1989.

Table IV. Chinook and Steelhead Spawning Utilization and Cost (per Redd) of Providing Spawning Habitat with Instream Structures.

Structure	Spawn Area m^2/structure	Utilization Coeff. King	Utilization Coeff. Sthd	Cost/Redd
FBW	7.6	-0.129	0.071	$ 4.29
LBW	95.5	1.826	-0.071	$ 2.07
SBW-B	34.0	-0.475	-0.204	$269.09
SBW-I	6.7	-0.849	0.235	$126.09
BLG	1.1	-0.672	-0.598	$127.96
BGW	2.2	1.393	4.399	$ 8.60
BRG	0.3	1.393	4.399	$ 78.82
BLD	28.2	10.477	-1.000	$ 0.44
RWD	0.0	N/A	N/A	N/A

Boulder Weirs provided complex habitat combinations in every circumstance (Figure 13).

South Fork Salmon large boulder weirs changed habitat structure from low gradient riffle to a complex of riffle, run, glide, and several pool types. Volume of available habitat increased over 40% compared to the same surface area of "pre-modified" habitat

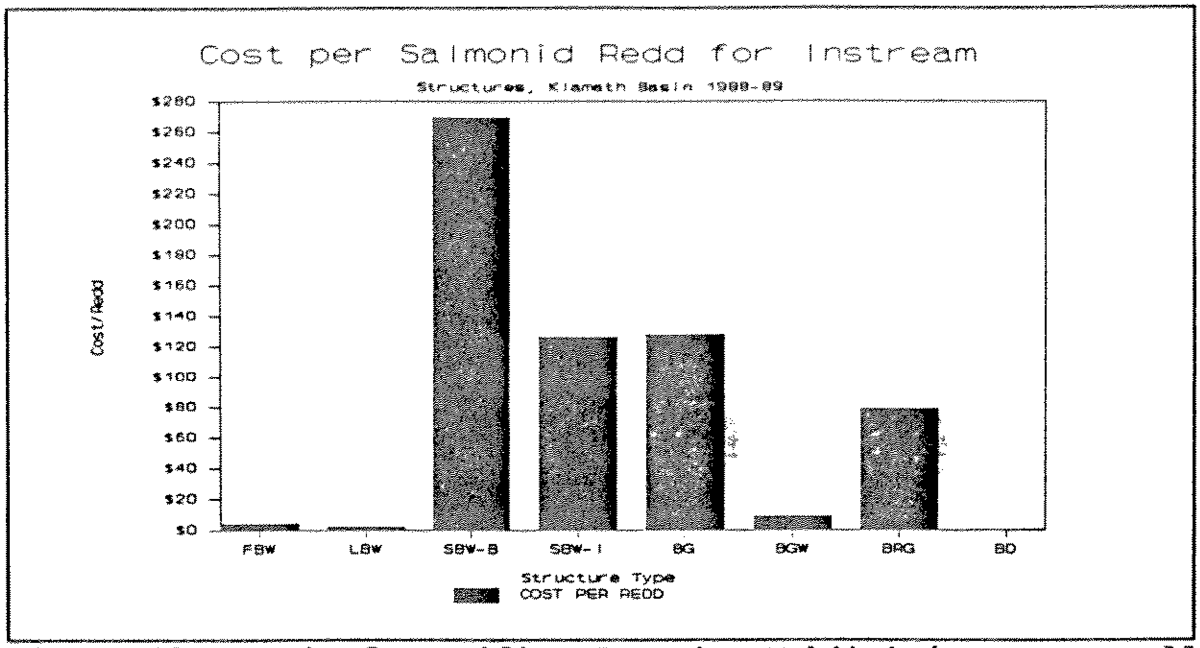

Figure 12. Cost of Providing Spawning Habitat (on a per redd basis) by Placement of Instream Structures, Klamath Basin, Calif.

(low gradient riffle). Cost per unit habitat area was moderately high ($0.361). Available spawning area dramatically increased (Figure 10), possibly because there is a significant bedload movement in this project area. Chinook salmon spawners heavily used spawning gravels associated with these structures (Figure 11;Table IV) resulting in high utilization coefficients. Steelhead spawners used gravels associated with these structures, but they did not select that habitat strongly as evidenced by utilization coefficients near 0. If those rates of use continued over the estimated life of these structures, spawning habitat would be provided for a reasonable cost ($2.07/redd; Figure 12;Table IV).

Though juvenile steelhead were found rearing around these structures (generally in the higher velocity habitats), none of the species or age classes of juvenile fish present selected this structure habitat over naturally available habitats (Table III). Limited juvenile fish use resulted in a relatively high cost per fish reared ($1.78; Table II).

Beaver Creek small boulder weirs were the most expensive structures investigated because of high construction costs. Cost per unit habitat area was the highest ($0.981) of any structure we evaluated. These weirs changed habitat structure from low gradient riffle into a complex of riffle, glide, and several pool types (Figure 13). Available spawning area was increased as a result of backfilling structures with spawning gravels. Chinook and steelhead spawners used gravels associated with these structures, but they did not select these habitats strongly as indicated by poor utilization coefficients (Figure 11;Table IV). If that rate of use continued over the estimated structure life, spawning habitat would be provided at the highest cost for any structure investigated ($269.09/redd; Figure 12;Table IV).

Volume of available habitat substantially increased (+85.4%) compared to the same surface area of "pre-modified" habitat (low gradient riffle). Unfortunately, resultant habitats were predominantly slower velocity types, favored only by young-of-the-year juvenile steelhead, as indicated by positive utilization coefficient for that cohort (Table III). Though schools of juvenile salmon were observed in these slow velocity areas early in the study period they did not select structure habitat over naturally available habitats (Table III). Limited juvenile fish **use resulted in the highest "cost per fish reared" ($18.85;Table II) of any structure investigated.**

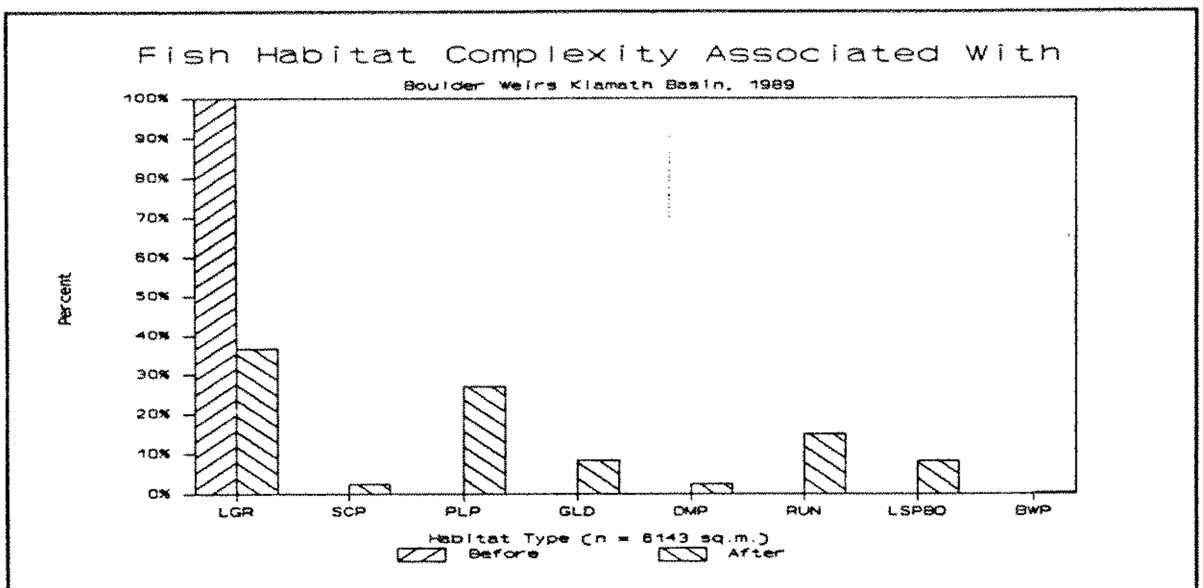

Figure 13. Fish Habitat Complexity Associated with Boulder Weirs, Klamath Basin 1989.

Indian Creek small boulder weirs were in the best physical condition (for their age) of any weir we inspected. As a result, estimated structure life was the longest of any weir (Table II). Cost per unit habitat area was the lowest ($0.264) of any weir we evaluated. Available spawning area increased (Figure 10), and though chinook and steelhead spawners used gravels associated with these structures, they did not select that habitat strongly as evidenced by utilization coefficients near 0 (Figure 11). If that low rate of use continued over the long estimated life of these structures, spawning habitat provided would still be costly ($126.09/redd; Table IV; Figure 12).

Indian Creek weirs resulted in high velocity habitat types (riffle, run, and lateral scour pool; Figure 13), selected by juvenile steelhead (yearlings) and coho (Table III). Chinook salmon were observed in dammed pool habitat (the only slow velocity habitat) associated with these weirs. Volume of available habitat increased about 20% compared to the same surface area of "pre-modified" habitat. High fish use and low structure cost resulted in the lowest "cost per fish reared" ($0.41/fish; Table II) we found in any weir modified habitat studied. These weirs reared more juvenile steelhead and salmon than any other structure investigated.

Boulder Groups, Boulder Groups with Wood, and Boulder Rootwad Groups resulted in more diverse habitat than that available prior to placement (Figure 14). Habitat volume was slightly increased by these structures if they did not have rootwads associated with them. Boulder rootwad groups slightly reduced the amount of habitat available.

Boulder Groups (Indian Creek) increased available spawning area (Figure 10), and though chinook and steelhead spawners used gravels associated with these structures, they did not select that habitat strongly as indicated by utilization coefficients near 0 (Figure 11). If that low rate of use continued over the estimated structure life, spawning habitat provided would be costly ($127.96/redd; Figure 12). Turbulent habitat types associated with Indian Creek Boulder Groups (riffle and pocket water; Figure 14), surprisingly were not selected by juvenile steelhead or salmon (Table III). Although juvenile fish did not utilize these habitats at a level above average, long estimated structure life and large affected surface area resulted in a very favorable cost per fish reared ($0.63; Table II), assuming juvenile fish use remains similar to what we observed. Cost per unit habitat area was the second lowest ($0.063) of any structure we evaluated.

Chinook and steelhead spawners selectively used pocket water (PKT) habitat associated with boulder groups with wood and boulder rootwad groups in the South Fork Salmon (Figure 11). The highest steelhead spawner utilization observed during this study (4.39;Figure 11) was associated with these structures placed in the South Fork Salmon River. If that rate of use continued over the estimated life of Boulder Groups with Wood, spawning habitat provided would be relatively low cost ($8.60/redd;Table IV;Figure 12). Though spawners selectively used Boulder/Rootwad Groups relatively little spawning habitat was provided by those structures (Table IV), which resulted in a high cost per redd ($78.82). Higher velocity habitat types associated with boulder groups with wood and boulder rootwad groups in the South Fork Salmon (riffle and pocket water; Figure 14), were selected by juvenile steelhead and chinook salmon (Table III). The highest juvenile chinook utilization we observed during this study was associated with these woody structures (Table III). Though juvenile use was very high, relatively short estimated structure life and nominal affected surface areas resulted in disappointing costs per fish reared (Table II). Cost per unit habitat area was relatively high for boulder groups with wood ($0.504) and slightly lower for boulder/rootwad groups ($0.372).

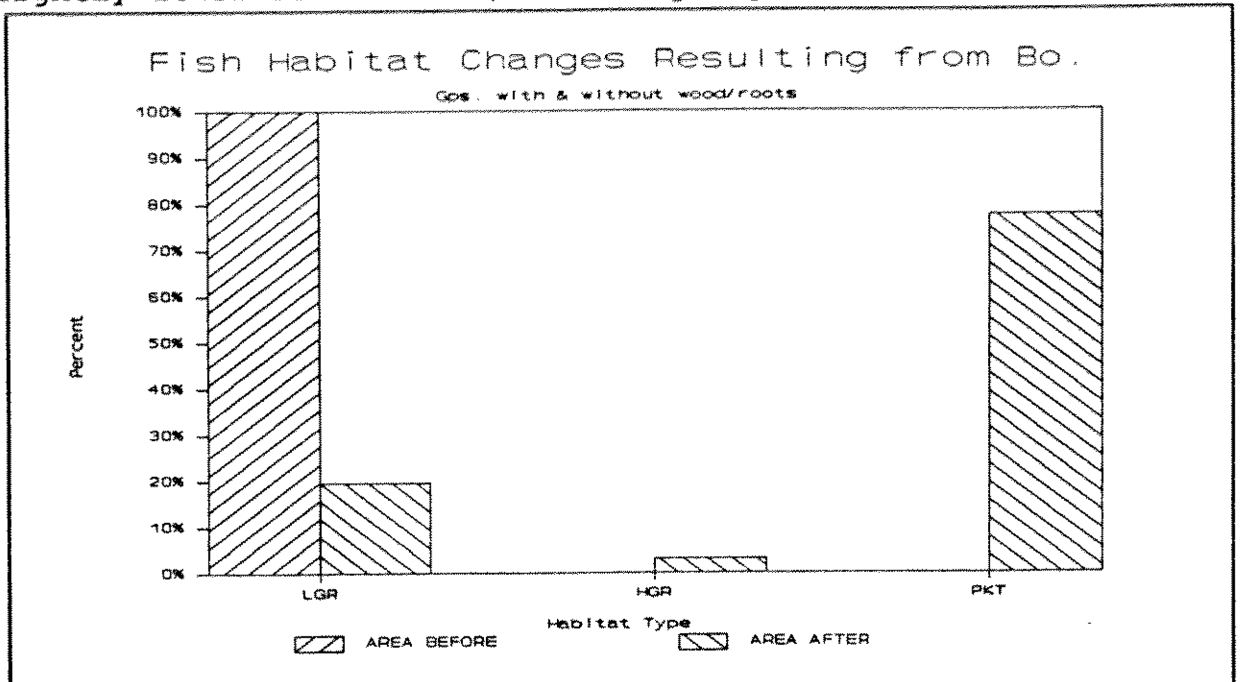

Figure 14. Fish Habitat Changes Resulting from Boulder Groups, Boulder Groups with Wood, and Boulder Rootwad Groups, Klamath Basin 1989.

Boulder Deflectors and Boulder/Rootwad Deflectors provided diverse habitat conditions (Figure 15) and also increased habitat volume by about 16%. Chinook spawners selectively used structure associated spawning habitats in the South Fork Salmon. Conversely, steelhead spawners avoided using these structures, as indicated by the maximum negative utilization coefficient possible (Table IV). Available spawning area was increased (Figure 10) by Boulder Deflectors, but was absent from Boulder/Rootwad Deflectors in the East Fork Salmon. **Chinook salmon spawners used spawning areas associated with Boulder Deflectors more (Figure 11) than any other habitat resulting in the highest spawning utilization coefficients observed (10.477;Table IV)** during this study. Both structure types had very long estimated lifespans because of their existing condition and location in the channel (bank associated, away from thalweg impacts). **Chinook spawner use and long structure lifespan resulted in Boulder Deflectors providing the lowest cost spawning habitat ($0.44/redd;Figure 12).** Since no spawning habitat was associated with Boulder/Rootwad Deflectors, it was not possible to estimate their long-term effectiveness at providing spawning area.

Boulder deflectors in the South Fork Salmon had a very low cost per fish reared ($0.48; Table II) because of high juvenile fish use. Above average juvenile salmon and steelhead use is also reflected by positive utilization coefficients for all cohorts (Table III). Cost per unit habitat area was also very low ($0.083) for these structures. Conversely, boulder rootwad deflectors had relatively high cost per fish reared ($1.76; Table II) due to low fish use, reflected by negative utilization coefficients (Table III). These structures had a relatively high cost per unit habitat area ($0.363).

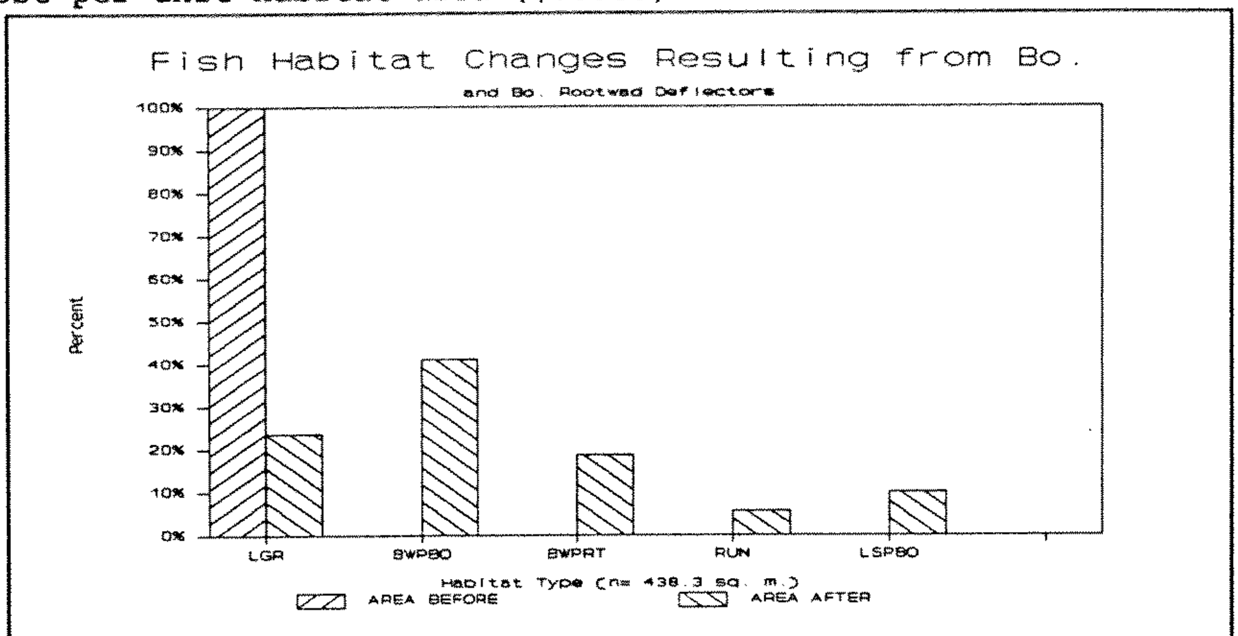

Figure 15. Fish Habitat Changes Resulting from Boulder Deflectors and Boulder/Rootwad Deflectors, Salmon Subbasin 1989.

DISCUSSION AND CONCLUSIONS

Weirs were the most expensive structures investigated, due to construction costs. Unfortunately, this high initial investment generally did not affect a large enough surface area of habitat to make cost per unit of affected habitat very reasonable. We expected that, due to the long estimated structure life of some of these structures, cost per unit affected habitat would be more reasonable. Conversely, cabled cover logs and digger logs (the lowest cost structures) affected large enough surface areas to make them very cost effective at altering physical habitat condition. Mid-cost range structures, those around $300 each, varied in their cost per unit at providing habitat. We believe that cost of physically modifying habitat area is only one factor that should be seriously considered when planning habitat restoration. However that factor is important enough to effect success or failure of a large scale habitat restoration program. Assuming all other factors are of equal weight, lowest cost structures can provide the "best value". Most importantly, any consideration of structural restoration should be driven by specific objectives based on sound assessment of habitat condition, species needs, and historical condition of the resources.

Estimates of structure life were used as an index for comparison between structure types. We believe functional life expectancy of structures could vary considerably in response to magnitude and duration of flow events, structure design and construction, and stream channel processes. Flow records compiled for the water years 1980 to 1989 reveal that the largest discharge event experienced during that period had a 10-15 year recurrence interval in 1982. Although boulder structures have been constructed on study tributaries since 1982, it is important to note that the average age of structures investigated is three years and the oldest five years. Peak flows measured since 1987 water year have not eexceeded a two year recurrence interval, total annual discharges have been below average.

We found that digger logs had the longest estimated functioal life expectancy. Because the digger log acts as a independent structural unit which remains to a large extent on the channel bank, we believe they should remain functional throughout the life of the wood. This structure type appeared ideally suited to the study site on Mill Creek, a moderately confined third order reach.

Life expectancy of cover logs was less than half that estimated for digger logs due to their reliance upon cable anchors. Because of this, we assumed cable life regulated functional life expectancy for these structures. We also noted that cover provided declined as the structure aged, due to loss of limbs and foliage.

Most boulder structures evaluated had long (40-50 years) life expectancies. Small boulder weirs, boulder groups, boulder deflectors, and boulder/rootwad deflectors were among the oldest structures evaluated, yet maintained high (>88%) structural integrity. Boulder groups associated with wood and rootwads had reduced life expectancies due to cable life. Large boulder weirs located on South Fork Salmon had the lowest estimated life expectancy probably because of high stream energy and mobile nature of the streambed at the project site. Free boulder weirs, located on Elk Creek, showed reduced structural integrity due to scour along the unkeyed margins.

We believe that structures composed of oversized boulders (those which do not require cabling) will maintain best structural integrity and have the longest useful structure life. Life expectancy of organic materials incorporated into these structures depend on anchor life and location in the channel. Digger logs of substantial size relative to channel width will provide long structure life with minimal maintainance. In the event that structural integrity is lost, least complicated structures built from native materials (large logs and boulders) will continue to provide habitat complexity as individual components. Selection of structure materials should be critically considered, especially where channels are subjected to frequent changes. **We believe use of natural materials to mimic naturally occurring channel features is key to success of habitat restoration.**

Important as physical habitat condition and structure cost may be, fish response (adult or juvenile, depending on original objective) to habitat modification should be a principal concern.

Modification prescribed to restore stable spawning habitat needs close scrutiny. We believe it is essential to know not only how much spawning habitat is available, but how the existing habitat is used by spawners (eg: 90% of spawning occurs in 5% of the available habitat). Prescribing habitat modification which results in additional spawning habitat may be justified, even if there appears to be an adequate quantity of habitat available. Use of habitat by spawners may not be directly proportional to the amount of it available. Therefore, use of a density dependent index (ie: spawner utilization coefficients) may not be appropriate in all circumstances. Such a prescription may be warranted if the habitat being selected by spawners is in short supply. **Several seasons of spawning area utilization surveys identifying where redds are located (in what habitat associations) and quantifying available spawning habitat during each spawning period is prerequisite to formulating an acceptable prescription.**

Location of gravels in or close to the thalweg associated with large boulder weirs on South Fork Salmon River may have been responsible for above average use by chinook spawners. Boulder deflectors were best utilized by chinook salmon spawners, probably because they resulted in gravel accumulations close to the thalweg, provided overhead cover (surface turbulence), or were near naturally occurring cover (riparian vegetation near the water surface) and shade. Chinook spawner use of "traditional" spawning enhancement structures (weirs backfilled with gravel) relative to their cost and amount of habitat they provided was disappointing. **Backfilling of instream structures with suitable gravel is a practice that should be discontinued until furthur investigation proves that it is warranted.**

Where steelhead spawning habitat restoration is justified by spawner use assessment, use of structures which result in "pocket water" type spawning areas may be the best tool. This habitat configuration proved most desirable when woody object cover was readily available to spawners. **The highest steelhead spawner utilization observed during this study was associated with boulder groups with wood and boulder/rootwad groups.**

Success of modifications prescribed to enhance juvenile rearing conditions should be determined by how well juvenile fish respond to that modification compared against a previously established control habitat. **Generally we found structures which provided high habitat and cover diversity received the best response from juvenile fish.** Comparisons against a control habitat must be made using an accepted method in which comparison units are equal (eg: fish per m^2 or fish per m^3). We observed fish use over one season, summer, when water temperatures were ideal for observation and fish activity. We saw dramatic changes in fish use even through this short time period, however those use changes were very irregular and no consistent pattern was found. Sampling habitats throughout the study basins may have better described changes in observed standing fish crops due to habitat availability (volume), suitability (temperature), and/or seasonal fish migration patterns. Fish rearing needs during other seasons may differ substantially from summer needs. Obviously, providing habitat conditions which meet the highest number of fish needs is key to success of restoration. Suitability of structurally modified habitat probably changes throughout the year, possibly changing diurnally as well. This question should be investigated in greater depth before conclusions can be drawn.

Digger logs, one of the least costly and simplest structures, provided the best increase in fish standing crop (fish/m^2) for the lowest cost. **We believe digger logs, were well used by rearing fish because they are one of the most natural restoration structures investigated.** Other structures which were well used (small weirs, deflectors, and boulder groups with attached wood) also seem to closely duplicate naturally productive habitats. Turbulent habitat types associated with boulder groups with wood, boulder rootwad groups, and boulder deflectors in the South Fork Salmon (riffle and pocket water), were specifically selected by juvenile steelhead and chinook salmon. **Providing overhead cover, especially if it extends into the water where it may also be used as object cover, seemed most valuable for juvenile steelhead and salmon if it was placed in a habitat type which would normally receive high fish use.** Placement of object cover in slow velocity areas (pool and glide edges) had questionable value for summer rearing habitat restoration. We believe water velocity reduction, resulting from dense branch structure of placed cover logs, may have made summer rearing habitat less desirable, especially for velocity seeking juvenile steelhead. We do not know what value these structures may have during cold water, high flow periods when fish may seek slow velocity, densely-covered habitats.

Cost effectiveness of habitat modification, as implied by the previous discussion, is a complex question to answer. We define the most cost effective method as one that meets stated restoration objectives providing the greatest increase in fish use (per surface area or volume) over the longest time period for the lowest cost.

Based on our definition of cost effectiveness we rank structures evaluated in this study (from most cost-effective to least cost effective) as follows:

1 - Digger Logs (Mill Creek)
2 - Boulder Deflectors (South Fork Salmon River)
3 - Small Boulder Weirs (Indian Creek)
4 - Boulder Groups with Woody Cover (South Fork Salmon River)
5 - Free Boulder Weirs (Elk Creek)
6 - Large Boulder Weirs (South Fork Salmon River)
7 - Boulder Groups (Indian Creek)
8 - Boulder/Rootwad Groups (South Fork Salmon River)
9 - Boulder/Rootwad Deflectors (East Fork Salmon)
10- Small Boulder Weirs (Beaver Creek)
11- Cabled Cover Logs (South and East Fork Salmon)

RECOMMENDATIONS

A) Consideration of structural restoration should be driven by specific objectives based on sound assessment of habitat condition, species, seasonal fish needs, life history stage specific requirements (alevin, fry, parr, smolt, adult), and historical condition of the resources.

B) We believe it is essential to know how much spawning habitat is available and how the existing habitat is used by spawners. Several seasons of spawning area utilization surveys identifying where redds are located (in what habitat associations, reaches, channel types, etc.) and quantifying available spawning habitat during each spawning period is prerequisite to formulating an acceptable spawning area restoration prescription.

C) Backfilling of instream structures with spawning gravel is a practice that should be discontinued until furthur investigation proves that it is warranted.

D) Use natural methods that most closely duplicate heavily used unmodified habitats providing woody object cover for spawning adults and rearing juvenile fish.

E) Provide the highest habitat and cover diversity possible for spawning adults and rearing juvenile fish.

F) Evaluation of habitat modifications are essential to eliminate poor techniques. Year-round comparisons against a control habitat must be made using an accepted method in which comparison units are equal (eg: fish per m^2 or fish per m^3).

G) Success or failure of projects should be determined based on cost effectiveness and meeting stated restoration objectives.

H) Historical records suggest that large woody debris played a key role in controlling channel features in many Pacific Coast streams. We believe the interaction of large woody debris/channel processes/fish utilization in tributaries to the Klamath River should be furthur investigated through implementation/evaluation of future restoration projects and a review of historic channel conditions.

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